UNIT **1**

The Problem of Stormwater Runoff

Introduction

"A stench from its inky surface putrescent with the oxidizing processes to which the shadows of the over-reaching trees add stygian blackness and the suggestion of some mythological river of death. With this burden of filth the purifying agencies of the stream are prostrated; it lodges against obstructions in the stream and rots, becoming hatcheries of mosquitoes and malaria. A thing of beauty is thus transformed into one of hideous danger."

Texas Department of Health 1925

CONTENTS

OVERVIEW: THE PROBLEM OF STORMWATER RUNOFF

The vivid description, above, of the Trinity River as it flowed through Fort Worth and Dallas, TX, in 1925 is no longer appropriate. The acute pollution problems that occurred in the Trinity River and throughout the United States before the 1970s have been visibly and dramatically improved. The creation of the U.S. Environmental Protection Agency (EPA) and the passage of the Clean Water Act (CWA) in 1972 resulted in improved treatment of municipal and industrial wastewaters, new and more stringent water quality criteria and standards, and an increased public awareness of water quality issues. During the first 18 years of the CWA, regulatory efforts, aimed at pollution control, focused almost entirely on point source, end-of-pipe, wastewater discharges. However, during this same period, widespread water quality monitoring programs and special studies conducted by state and federal agencies and other institutions implicated nonpoint sources

(NPS) as a major pollutant category, affecting most degraded waters around the country. For example, in Ohio 51% of the streams assessed were thought to be adversely impacted by NPS pollution. Nonpoint source pollution presents a challenge from both a regulatory and an assessment perspective. Unlike many point source discharges, pollution inputs are not constant, do not reoccur in a consistent pattern (i.e., discharge volume and period), often occur over a diffuse area, and originate from watersheds whose characteristics and pollutant loadings vary through time. Given this extreme heterogeneity, simple solutions to NPS pollution control and the assessment of ecosystem degradation are unlikely. Fortunately, methods do exist to accomplish both control and accurate assessments quite effectively. To accomplish this, however, one must have a clear understanding of the nature of the problem, the pollutant sources, the receiving ecosystem, the strengths and weaknesses of the assessment tools, and proper quality assurance (QA) and quality control (QC) practices. This handbook will discuss these issues as they pertain to assessing stormwater runoff effects on freshwater ecosystems.

SOURCES OF NPS POLLUTION

A wide variety of activities and media comprise NPS pollution in waters of the United States (Table 1.1). The major categories of sources include agriculture, silviculture, resource extraction, hydro-modification, urban areas, land disposal, and contaminated sediments. The contribution of each category is, of course, a site-specific issue. In Ohio, as in many midwestern and southern states, agriculture is the principal source of NPS stressors, as shown in Table 1.2 (ODNR 1989).

These stressors include habitat destruction (e.g., channelization, removal of stream canopy and riparian zone, loss of sheltered areas, turbidity, siltation) and agrichemicals (e.g., pesticides and nutrients). In urban areas, stream and lake impairment is also due to habitat destruction; but, in addition, physical and chemical contaminant loadings come from runoff from impervious areas (e.g., parking lots, streets) of construction sites, and industrial, commercial, and residential areas. Numerous studies (such as May 1996) have examined the extent of urbanization in relation to decaying receiving water conditions (Figure 1.1). Other contaminant sources that have been doc-

Table 1.1   Nonpoint Source Pollution Categories and Subcategories

Category: Agriculture	Category: Hydromodification
General agriculture	General hydromodification
Crop production	Channelization
Livestock production	Dredging
Pasture	Dam construction
Specialty crop production	Stream bank modification
Category: Silviculture	Bridge construction
General silviculture	**Category: Urban**
Harvesting, reforestation	General urban
Residue management	Storm sewers
Road construction	Sanitary sewers
Forest management	Construction sites
Category: Resource Extraction	Surface runoff
General resource extraction	**Category: Land Disposal**
Surface coal mining	General land disposal
Subsurface coal mining	Sludge disposal
Oil/Gas production	Wastewater
Category: In-place (Sediment) Pollutants	Sanitary landfills
	Industrial land treatment
	On-site wastewater treatment

From EPA. *Results of the Nationwide Urban Runoff Program.* Water Planning Division, PB 84-185552, Washington, D.C. December 1983.

Table 1.2 Major Categories of Nonpoint Source Pollution
Impacting Surface Water Quality in Ohio

Major Categories of Nonpoint Source Pollution	Stream Miles Affected	Percentage of Miles Affected
Agriculture	5300	44
Resource extraction	2000	17
Land disposal	1600	13
Hydromodification	1500	13
Urban	1100	9
Silviculture	400	3
In-place pollutants	100	1
Total stream miles affected	12,000	

From ODNR (Ohio Department of Natural Resources). Ohio Nonpoint Source Management Program. Ohio Department of Natural Resources, Columbus, OH. 1989.
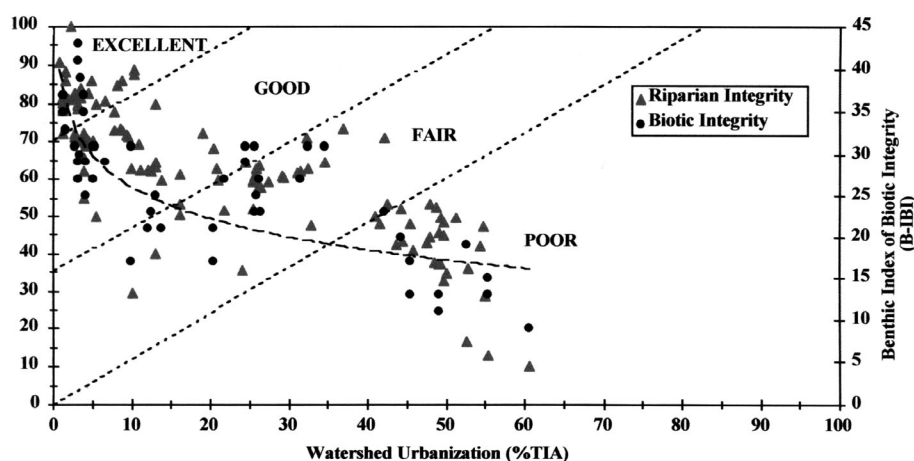

Figure 1.1 Relationship between basin development, riparian buffer width, and biological integrity in Puget Sound lowland streams. (From May, C.W. *Assessment of the Cumulative Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion: Implications for Salmonid Resource Management.* Ph.D. dissertation, University of Washington, Seattle. 1996. With permission.)

umented, but are even more difficult to assess, include accidental spills, unintended discharges, and atmospheric deposition.

The pollutants present in stormwater runoff vary with each watershed; however, certain pollutants are associated with specific activities (e.g., soybean farming, automobile service areas) and with area uses (e.g., parking lots, construction). By analyzing the land use patterns, watershed characteristics, and meteorological and hydrological conditions, an NPS assessment program can be focused and streamlined.

A number of studies have linked specific pollutants in stormwater runoff with their sources (Table 1.3). Pitt et al. (1995) reviewed the literature on stormwater pollutant sources and effects and also measured pollutants and sample toxicity from a variety of urban source categories of an impervious and pervious nature. The highest concentrations of synthetic organics were in roof runoff, urban creeks, and combined sewer overflows (CSOs). Zinc was highest from roof runoff (galvanized gutters). Nickel was highest in runoff from parking areas. Vehicle service areas produced the highest cadmium and lead concentrations, while copper was highest in urban creeks (Pitt et al. 1995). Most metals in stormwater runoff originate from streets (Table 1.4, FWHA 1987) and parking areas. Other metal sources include wood preservatives, algicides, metal corrosion, road salt, batteries, paint, and industrial electroplating waste. One large survey (EPA 1983) found only 13 organics occurring in at least 10% of the samples. The most common were 1,3-dichlorobenzene

Table 1.3 Potential Sources of Stormwater Toxicants

	Automobile Use	Pesticide Use	Industrial/Other
Halogenated Aliphatics			
Methylene chloride		Fumigant[a]	Plastics, paint remover, solvent
Methyl chloride	Leaded gas[a]	Fumigant[a]	Refrigerant, solvent
Phthalate Esters			
Di-N-butyl phthalate		Insecticide	Plasticizer[a], printing inks, paper, stain, adhesive
Bis (2-ethyhexyl) phthalate			Plasticizer[a]
Butylbenzyl phthalate			Plasticizer[a]
Polycyclic Aromatic Hydrocarbons			
Chrysene	Gasoline[a], oil/grease		
Phenanthrene	Gasoline		Wood/coal combustion[a]
Pyrene	Gasoline, oil, asphalt	Wood preservatives	Wood/coal combustion[a]
Volatiles			
Benzene	Gasoline[a]		Solvent formed from salt, gasoline and asphalt
Chloroform		Insecticide	Solvent, formed from chlorination[a]
Toluene	Gasoline[a], asphalt		Solvent
Heavy Metals			
Chromium	Metal corrosion[a]		Paint, metal corrosion, electroplating waste[a]
Copper	Metal corrosion, brake linings	Algicide	Paint, metal corrosion, electroplating waste[a]
Lead	Gasoline, batteries		Paint
Zinc	Metal corrosion, road salt, rubber[a]	Wood preservative	Paint, metal corrosion[a]
Organochlorides and Pesticides			
Lindane		Mosquito control[a] Seed pretreatment	
Chlordane		Termite control[a]	
Pentachlorophenol		Wood preservative	Paint Wood processing
PCBs			Electrical, insulation, paper adhesives
Dieldrin			
Diazinon			
Chlorpyrifos			
Atrazine			

[a] Most significant sources.

Modified from Callahan, M.A., et al., *Water Related Environmental Fates of 129 Priority Pollutants.* U.S. Environmental Protection Agency, Monitoring and Data Support Division, EPA-4-79-029a and b. Washington D.C. 1979; Verschueren, K. *Handbook of Environmental Data on Organic Chemicals,* 2nd edition. Van Nostrand Reinhold Co., New York. 1983.

Table 1.4 Highway Runoff Constituents and Their Primary Sources

Constituents	Primary Sources
Particulates	Pavement wear, vehicles, atmosphere, maintenance
Nitrogen, phosphorus	Atmosphere, roadside fertilizer application
Lead	Leaded gasoline (auto exhaust), tire wear (lead oxide filler material, lubricating oil and grease, bearing wear)
Zinc	Tire wear (filler materials), motor oil (stabilizing additive), grease
Iron	Auto body rust, steel highway structures (guard rails, etc.), moving engine parts
Copper	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides
Cadmium	Tire wear (filler material), insecticide application
Chromium	Metal plating, moving engine parts, break lining wear
Nickel	Diesel fuel and gasoline (exhaust), lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving
Manganese	Moving engine parts
Cyanide	Anticake compound (ferric ferrocyanide, sodium ferrocyanide, yellow prussiate of soda) used to keep deicing salt granular
Sodium, calcium, chloride	Deicing salts
Sulfate	Roadway beds, fuel, deicing salts
Petroleum	Spills, leaks, or blow-by of motor lubricants, antifreeze and hydraulic fluids, asphalt surface leachate
PCB	Spraying of highway rights-of-way, background atmospheric deposition, PCB catalyst in synthetic tires

From U.S. DOT, FHWA, Report No. FHWA/RD-84/056-060, June 1987.

and fluoranthene (23% of the samples). These 13 compounds were similar to those reported in most areas. The most common organic toxicants have been from automobile usage (polycyclic aromatic hydrocarbons, or PAHs), combustion of wood and coal (PAHs), industrial and home use solvents (halogenated aliphatics and other volatiles), wood preservatives (PAHs, creosote, pentachlorophenol), and a variety of agricultural, municipal, and highway compounds, and pesticides.

The major urban pollution sources are construction sites, on-site sewage disposal systems, households, roadways, golf courses, parks, service stations, and parking areas (Pitt et al. 1995). The primary pollutant from construction is eroded soils (suspended and bedload sediments, dissolved solids, turbidity), followed by hydrocarbons, metals, and fertilizers.

Silviculture is a major source of nonpoint pollution in many areas of the country. The primary pollutant is eroded soils, which result in elevated turbidity, silted substrates, altered habitat, higher dissolved solids, and altered ion ratios in the streams and lakes of the watershed. Water temperatures increase as tree canopies are removed and stream flow slows. Fertilizers and pesticides may also be used which are transported to the streams via surface runoff, groundwater, and drift.

Agricultural activities contribute a wide variety of stormwater pollutants, depending on the production focus and ecoregion. Major pollutants include eroded soils, fertilizers, pesticides, hydrocarbons (equipment-related), animal wastes, and soil salts.

The hydromodification category of NPS includes dredging, channelization, bank stabilization, and impoundments. Stormwaters obviously do not "run off" any of these sources, but stormwater (high flow) does degrade waters associated with these sources. Water quality parameters which may be affected by these sources during stormwater events include turbidity, sediment loading (habitat alteration), dissolved solids, temperature, nutrients, metals, synthetic organics, dissolved oxygen, pathogens, and toxicity.

Of a more site-specific nature, resource extraction, land waste disposal, and contaminated sediments are sources of pollutants during stormwater events. Activities such as sand and gravel, metal, coal, and oil and gas extraction from or near receiving waters may contribute to habitat alteration and increased turbidity, siltation, metals, hydrocarbons, and salt during storm events. Land waste disposal sources consist of sludge farm runoff, landfill and lagoon runoff and leachate, and on-site septic system (leachfield) overflows. These sources may contribute a variety of pollutants

to receiving waters such as nutrients, solids (dissolved and suspended), pathogens, metals, and synthetic organics. Contaminated sediments occur in numerous areas throughout the United States (EPA 1994). Many nutrients and toxic metals, metalloids, and synthetic organics readily sorb to particulates (organic or inorganic) which accumulate as bedded sediments. During storm events, these sediments may be resuspended and then become more biologically active by pollutant desorption, transformation, or particle uptake by organism ingestion.

The specific stormwater pollutants vary dramatically in their fate and effect characteristics. In most assessments of NPS pollution, there are many unknowns, such as:

- What are the pollutants of concern?
- What are the pollutant sources?
- What are the pollutant loadings?

These common unknowns provide the rationale for use of an integrated assessment strategy (see Unit 2) which incorporates several essential components of runoff-receiving water systems.

REGULATORY PROGRAM

In February 1987, amendments to the federal Clean Water Act (CWA) were passed by Congress and required states (Sections 101 and 319) to assess NPS pollution and develop management programs. These programs are to be tailored on a watershed-specific basis, although they are structured along political jurisdictions. There are also NPS requirements under Section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990. The EPA published the Phase 1 stormwater discharge regulations for the CWA in the *Federal Register* on November 16, 1990. The regulations confirm stormwater as a point source that must be regulated through permits issued under the National Pollutant Discharge Elimination System (NPDES). Certain specified industrial facilities and large municipalities (>100,000 population) fell under the Phase 1 regulations. The Phase 2 regulations were enacted in October 1999, requiring municipalities of 10,000 and greater to comply with stormwater control guidelines.

Monitoring activities must be part of the Phase 1 NPDES stormwater permit requirements. One monitoring element is a field screening program to investigate inappropriate discharges to the storm drainage system (Pitt et al. 1993). The Phase 1 requirements also specified outfall monitoring during wet weather to characterize discharges from different land uses. Specified industries are also required to periodically monitor their stormwater discharges. Much of the local municipal effort associated with the Phase 1 permit requirements involved describing the drainage areas and outfalls. Large construction sites are also supposed to be controlled, but enforcement has been very spotty. Local governments have been encouraged by the EPA to develop local stormwater utilities to pay for the review and enforcement activities required by this regulation. The Phase 2 permit requirements are likely to have reduced required monitoring efforts for small communities and remaining industries.

The Stormwater Phase 2 Rule was published in early November 1999 in the *Federal Register*. The purpose of the rule is to designate additional sources of stormwater that need to be regulated to protect water quality. Two new classes of facilities are designated for automatic coverage on a nationwide basis:

1. Small municipal separate storm sewer systems located in urbanized areas (about 3500 municipalities) [Phase 1 included medium and large municipalities, having populations greater than 100,000]
2. Construction activities that disturb between 1 and 5 acres of land (about 110,000 sites a year) [Phase 1 included construction sites larger than 5 acres]

There is also a new "no exposure" incentive for Phase 1 sites having industrial activities. It is expected that this will exclude about 70,000 facilities nationwide from the stormwater regulations. The NPDES permitting authority would need to issue permits (most likely general permits) by May 31, 2002.

Proposed construction site regulations in the Phase 2 rule include:

1. Ensure control of other wastes at construction sites (discarded building materials, concrete truck washout, sanitary wastes, etc.)
2. Implement appropriate best management practices (such as silt fences, temporary detention ponds, etc.)
3. Require preconstruction reviews of site management plans
4. Receive and consider public information
5. Require regular inspections during construction
6. Have penalties to ensure compliance

If local regulations incorporate the following principles and elements into the stormwater program, they would be considered as "qualifying" programs that meet the federal requirements:

Five Principles
1. Good site planning
2. Minimize soil movement
3. Capture sediment
4. Good housekeeping practices
5. Mitigation of post-construction stormwater discharges

Eight Elements
1. Program description
2. Coordination mechanism
3. Requirements for nonstructural and structural BMPs
4. Priorities for site inspections
5. Education and training
6. Exemption of some activities due to limited impacts
7. Incentives, awards, and streamlining mechanisms
8. Description of staff and resources

Unfortunately, many common stormwater parameters which cause acute and chronic toxicity or habitat problems are not included in typical monitoring programs conducted under the NPDES stormwater permit program. Therefore, stormwater discharges that are degrading receiving waters may not be identified as significant outfalls from these monitoring efforts. Conversely, these data may suggest significant pollution is adversely affecting receiving waters, when in fact it is not. As discussed later in this book, the recent promotion and adoption of integrated assessment approaches which utilize stream biological community indices, toxicity, and habitat characterization of receiving waters provide much more reliable data on stormwater discharge effects and water quality.

Section 304 of the CWA directs EPA to develop and publish information on methods for measuring water quality and establishing water quality criteria for toxic pollutants. These other approaches include biological monitoring and assessment methods which assess the effects of pollutants on aquatic communities and factors necessary to restore and maintain the chemical, physical, and biological integrity of all waters. These "toolboxes" are intended to enable local users to make more efficient use of their limited monitoring resources. Of course, a primary purpose of this book is also to provide guidance to this user community. As such, it is hoped that this book can be considered a "super" toolbox, especially with its large number of references for additional information and its detailed case studies.

APPLICATIONS OF THE HANDBOOK

The first aspect of designing a monitoring program is describing how the data are to be used. This may include future uses of the data and must also include the necessary quality of the data (allowable errors). Many uses of the data may be envisioned, as shown in the following brief discussion. Data may be used in the evaluation of local stormwater problems (risk assessments) and identification of pollutant sources to support a comprehensive stormwater management program, compliance monitoring required by regulations, model calibration and verification for TMDL (total maximum daily load) evaluations, evaluation of the performance of control practices, screening analyses to identify sources of pollutants, etc. It is critical that an integrated assessment approach (designed on a site-specific basis) be used to improve the validity of the assessment and its resulting conclusions. Critical aspects of this are discussed below.

Stormwater Management Planning (Local Problem Evaluations and Source Identifications)

Stormwater management planning encompasses a wide range of site-specific issues. The local issues that affect stormwater management decisions include understanding local problems and the sources of pollutants or flows that affect these problems. Local monitoring therefore plays an important role in identifying local problems and sources.

The main purpose of treating stormwater is to reduce its adverse impacts on receiving water beneficial uses. Therefore, it is important in any stormwater runoff study to assess the detrimental effects that runoff is actually having on a receiving water. Receiving waters may have many beneficial use goals, including:

- Stormwater conveyance (flood prevention)
- Biological uses (warm water fishery, biological integrity, etc.)
- Noncontact recreation (linear parks, aesthetics, boating, etc.)
- Contact recreation (swimming)
- Water supply

As discussed in Chapter 2, it is unlikely that any of these uses can be fully obtained with full development in a watershed and with no stormwater controls. However, the magnitude of these effects varies greatly for different conditions. Obviously, local monitoring and evaluation of data are needed to describe specific local problems, especially through the use of an integrated monitoring approach that considers physical, chemical, and biological observations collectively. As described throughout this book, relying only on a single aspect of receiving water conditions, or applying general criteria to local data, can be very misleading, and ultimately expensive and ineffective.

After local receiving problems are identified, it is necessary to understand what is causing the problems. Again, this can be most effectively determined through local monitoring. Runoff is comprised of many separate source area flow components and phases that are discharged through the storm drainage system and includes warm weather stormwater, snowmelt, baseflows, and inappropriate discharges to the storm drainage ("dry-weather" flows). It may be important to consider all of these potential urban flow discharges when evaluating alternative stormwater management options.

It may be adequate to consider the combined outfall conditions alone when evaluating the long-term, area-wide effects of many separate outfall discharges to a receiving water. However, if better predictions of outfall characteristics (or the effects of source area controls) are needed, then the separate source area components must be characterized. The discharge at an outfall is made up of a mixture of contributions from different source areas. The "mix" depends on the characteristics

of the drainage area and the specific rain event. The effectiveness of source area controls is therefore highly site and storm specific.

Risk Assessments

Risk assessments contain four major components (NRC 1983):

- Hazard identification
- Effects characterization
- Exposure characterization
- Risk characterization

Hazard identification includes quantifying pollutant discharges, plus modeling the fate of the discharged contaminants. Obviously, substantial site-specific data are needed to prepare the selected model for this important aspect of a risk assessment. Knowledge about the mass and concentration discharges of a contaminant is needed so the transport and fate evaluations of the contaminant can be quantified. Knowledge of the variations of these discharges with time and flow conditions is needed to determine the critical dose–response characteristics for the contaminants of concern. A suitable model, supported by adequate data, is necessary to produce the likely dose–stressor response characteristics. Exposure assessment is related to knowledge of the users of receiving waters and contaminated components (such as contaminated fish that are eaten, contaminated drinking water being consumed, children exposed to contaminated swimming by playing in urban creeks, etc.). Finally, the risk is quantified based on this information, including the effects of all of the possible exposure pathways. Obviously, many types of receiving water and discharge data are needed to make an appropriate risk assessment associated with exposure to stormwater, especially related to discharge characteristics, fate of contaminants, and verification of contaminated components. The use of calibrated and validated discharge and fate models is therefore necessary when conducting risk assessments.

Total Maximum Daily Load (TMDL) Evaluations

The total maximum daily load (TMDL) for a stream is the estimated maximum discharge that can enter a water body without affecting its designated uses. TMDLs can be used to allocate discharges from multiple sources and to define the level of control that may be needed. Historically, assimilative capacities of many receiving waters were based on expected dissolved oxygen conditions using in-stream models. Point source discharges of BOD were then allocated based on the predicted assimilative capacity. Allowed discharges of toxic pollutants can be determined in a similar manner. Existing background toxicant concentrations are compared to water quality criteria under critical conditions. The margin in the pollutant concentration (difference between the existing and critical concentrations) is multiplied by the stream flow to estimate the maximum allowable increased discharge, before the critical criteria would likely be exceeded. There has always been concern about margins of safety and other pollutant sources in the simple application of assimilative capacity analyses. The TMDL process is a more comprehensive approach that attempts to examine and consider all likely pollutant sources in the watershed. The EPA periodically publishes guidance manuals describing resources available for conducting TMDL analyses (Shoemaker et al. 1997, for example).

Model Calibration and Validation

A typical use of stormwater monitoring data is to calibrate and validate models that can be used to examine many questions associated with urbanization, especially related to the design of

control programs to reduce problem discharges effectively. All models need to be calibrated for local conditions. Local rain patterns and development characteristics, for example, all affect runoff characteristics. Calibration usually involves the collection of an initial set of data that is used to modify the model for these local characteristics. Validation is an independent check to ensure that the calibrated model produces predictions within an acceptable error range. Unfortunately, many models are used to predict future conditions that are not well represented in available data sets, or the likely future conditions are not available in areas that could be monitored. These problems, plus many other aspects of modeling, require someone with good skill and support to ensure successful model use.

Model calibration and validation involves several steps that are similar for most stormwater modeling processes. The best scenario may be to collect all calibration information from one watershed and then validate the calibrated model using independent observations from another watershed. Another common approach is to collect calibration information for a series of events from one watershed, and then validate the calibrated model using additional data from other storms from the same watershed. Numerous individual rainfall-runoff events may need to be sampled to cover the range of conditions of interest. For most stormwater models, detailed watershed information is also needed. Jewell et al. (1978) presented one of the first papers describing the problems and approaches needed for calibrating and validating nonpoint source watershed scale models. Most models have descriptions of recommended calibration and validation procedures. Models that have been used for many years (such as SWMM and HSPF) also have many publications available describing the sensitivity of model components and the need for adequate calibration.

It is very important that adequate QA/QC procedures be used to ensure the accuracy and suitability of the data. Common problems during the most important rainfall-runoff monitoring activities are associated with unrepresentative rainfall data (using too few rain gauges and locating them incorrectly in the watershed), incorrect rain gauge calibrations, poor flow-monitoring conditions (surcharged flows, relying on Manning's equation for V and Q, poor conditions at the monitoring location), etc. The use of a calibrated flume is preferred, for example. Other common errors are associated with inaccurate descriptions of the watershed (incorrect area, amount of impervious area, understanding of drainage efficiency, soil characteristics, etc.). Few people appreciate the inherent errors associated with measuring rainfall and runoff. Most monitoring programs are probably no more than ±25% accurate for each event. It is very demanding to obtain rainfall and runoff data that is only 10% in error. This is most evident when highly paved areas (such as shopping centers or strip commercial areas) are monitored and the volumetric runoff coefficients are examined. For these areas, it is not uncommon for many of the events to have volumetric runoff coefficient (Rv) values greater than 1.0 (implying more runoff than rainfall). Similar errors occur with other sites but are not as obvious.

Data from several watersheds are available for the calibration and validation process. If so, start with data from the simplest area (mostly directly connected paved areas and roofs, with little unpaved areas). This area probably represents commercial roofs and parking/storage areas alone. These areas should be calibrated first, before moving on to more complex areas. The most complex areas, such as typical residential areas having large expanses of landscaped areas and with most of the roofs being disconnected from the drainage areas, should be examined last.

Effectiveness of Control Programs

Effective stormwater management programs include a wide variety of control options that can be utilized to reduce receiving water problems. With time and experience, some of these will be found to be more effective than others. In order to identify which controls are most cost-effective for a specific area, local performance evaluations should be conducted. In many cases, straightforward effectiveness monitoring (comparing influent with effluent concentrations for a stormwater filter, for example) can be utilized, while other program elements (such as public education or street

cleaning) can be much more difficult to evaluate. Therefore, this book presents monitoring approaches that can be utilized for a broad range of control programs. These monitoring activities may appear to be expensive. However, the true cost of not knowing how well currently utilized controls function under local conditions can be much more costly than obtaining accurate local data and making appropriate changes in design methods.

The first concern when investigating alternative treatment methods is determining the needed level of stormwater control. This determination has a great effect on the cost of the stormwater management program and needs to be made carefully. Problems that need to be addressed range from sewerage maintenance issues to protecting many receiving water uses. As an example, Laplace et al. (1992) recommends that all particles greater than about 1 to 2 mm in diameter be removed from stormwater in order to prevent deposition in sewerage. The specific value is dependent on the energy gradient of the flowing water in the drainage system and the hydraulic radius of the sewerage. This treatment objective can be easily achieved using a number of cost-effective source area and inlet treatment practices. In contrast, much greater levels of stormwater control are likely needed to prevent excessive receiving water degradation. Typical treatment goals usually specify about 80% reductions in suspended solids concentrations. For most stormwaters, this would require the removal of most particulates greater than about 10 μm in diameter, about 1% of the 1 mm size noted above to prevent sewerage deposition problems. Obviously, the selection of a treatment goal must be done with great care.

There are many stormwater control practices, but not all are suitable in every situation. It is important to understand which controls are suitable for the site conditions and can also achieve the required goals. This will assist in the realistic evaluation for each practice of the technical feasibility, implementation costs, and long-term maintenance requirements and costs. It is also important to appreciate that the reliability and performance of many of these controls have not been well established, with most still in the development stage. This is not to say that emerging controls cannot be effective; however, there is not a large amount of historical data on which to base designs or to provide confidence that performance criteria will be met under the local conditions. Local monitoring can be used to identify the most effective controls based on the sources of the identified problem pollutants, and monitoring can be utilized to measure how well in-place controls are functioning over the long term. These important data can be used to modify recommendations for the use of specific controls, design approaches, and sizing requirements.

Compliance with Standards and Regulations

The receiving water (and associated) monitoring tools described in this book can also be used to measure compliance with standards and regulations. Numerous state and local agencies have established regulatory programs for moderate and large-sized communities due to the EPA's NPDES (National Pollutant Discharge Elimination System) stormwater permit program. The recently enacted Phase 2 regulations will extend some stormwater regulations to small communities throughout the United States. In addition, the increasing interest in TMDL evaluations in critical watersheds also emphasizes the need for local receiving water and discharge information. These regulatory programs all require certain monitoring, modeling, and evaluation efforts that can be conducted using procedures and methods described in this book.

REFERENCES

Callahan, M.A., M.W. Slimak, N.W. Gabel, I.P. May, C.F. Fowler, J.R. Freed, P. Jennings, R.L. Durfee, F.C. Whitmore, B. Maestri, W.R. Mabey, B.R. Holt, and C. Gould, *Water Related Environmental Fates of 129 Priority Pollutants.* U.S. Environmental Protection Agency, Monitoring and Data Support Division, EPA-4-79-029a and b. Washington D.C. 1979.

EPA. *Results of the Nationwide Urban Runoff Program.* Water Planning Division, PB 84-185552, Washington, D.C. December 1983.

EPA. *Procedures for Assessing the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates,* EPA 600/R-94/024, U.S. Environmental Protection Agency, Duluth, MN. 1994.

Jewell, T.K., T.J. Nunno, and D.D. Adrian. Methodology for calibrating stormwater models. *J. Environ. Eng. Div.* 104: 485. 1978.

Laplace, D., A. Bachoc, Y. Sanchez, and D. Dartus. Truck sewer clogging development — description and solutions. *Water Sci. Technol.* 25(8): 91–100. 1992.

May, C.W. *Assessment of the Cumulative Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion: Implications for Salmonid Resource Management.* Ph.D. dissertation, University of Washington, Seattle. 1996.

NRC (National Research Council). *Risk Assessment in the Federal Government: Managing the Process.* National Academy Press. Washington, D.C. 1983.

ODNR (Ohio Department of Natural Resources). Ohio Nonpoint Source Management Program. Ohio Department of Natural Resources, Columbus, OH. 1989.

Pitt, R.E., R.I. Field, M.M. Lalor, D.D. Adrian, D. Barbé, *Investigation of Inappropriate Pollutant Entries into Storm Drainage Systems: A User's Guide.* Rep. No. EPA/600/R-92/238, NTIS Rep. No. PB93-131472/AS, U.S. EPA, Storm and Combined Sewer Pollution Control Program, Edison, NJ. Risk Reduction Engineering Lab., Cincinnati, OH. 1993.

Pitt, R., R. Field, M. Lalor, and M. Brown. Urban stormwater toxic pollutants: assessment, sources and treatability. *Water Environ. Res.* 67(3): 260–275. May/June 1995.

Shoemaker, L., M. Lahlou, M. Bryer, D. Kumar, and K. Kratt. *Compendium of Tools for Watershed Assessment and TMDL Development.* EPA 841-B-97-006. U.S. Environmental Protection Agency. Office of Water. Washington, D.C. May 1997.

U.S. Department of Transportation (DOT). FHWA/RD-84/056-060, June 1987.

Verschueren, K. *Handbook of Environmental Data on Organic Chemicals,* 2nd edition. Van Nostrand Reinhold, New York. 1983.